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# (54) Temperature compensated crystal oscillators

(57) Apparatus for programming a PROM which stores temperature compensating data for a crystal oscillator 6 comprises means 7 for monitoring both the ambient temperature represented by the output of a digital to analogue converter 2 and also the output frequency of the crystal oscillator circuit 6, the temperature compensation input to a D/A converter 4 being adjusted until the monitored output frequency is at a predetermined desired frequency, and the final temperature compensation input being stored in the memory location at 3 addressed by the output of the analogue to digital converter 2. The appropriate temperature compensation signal is later selected from the memory 3 by the analogue to digital converter 2 in dependence upon the ambient temperature.

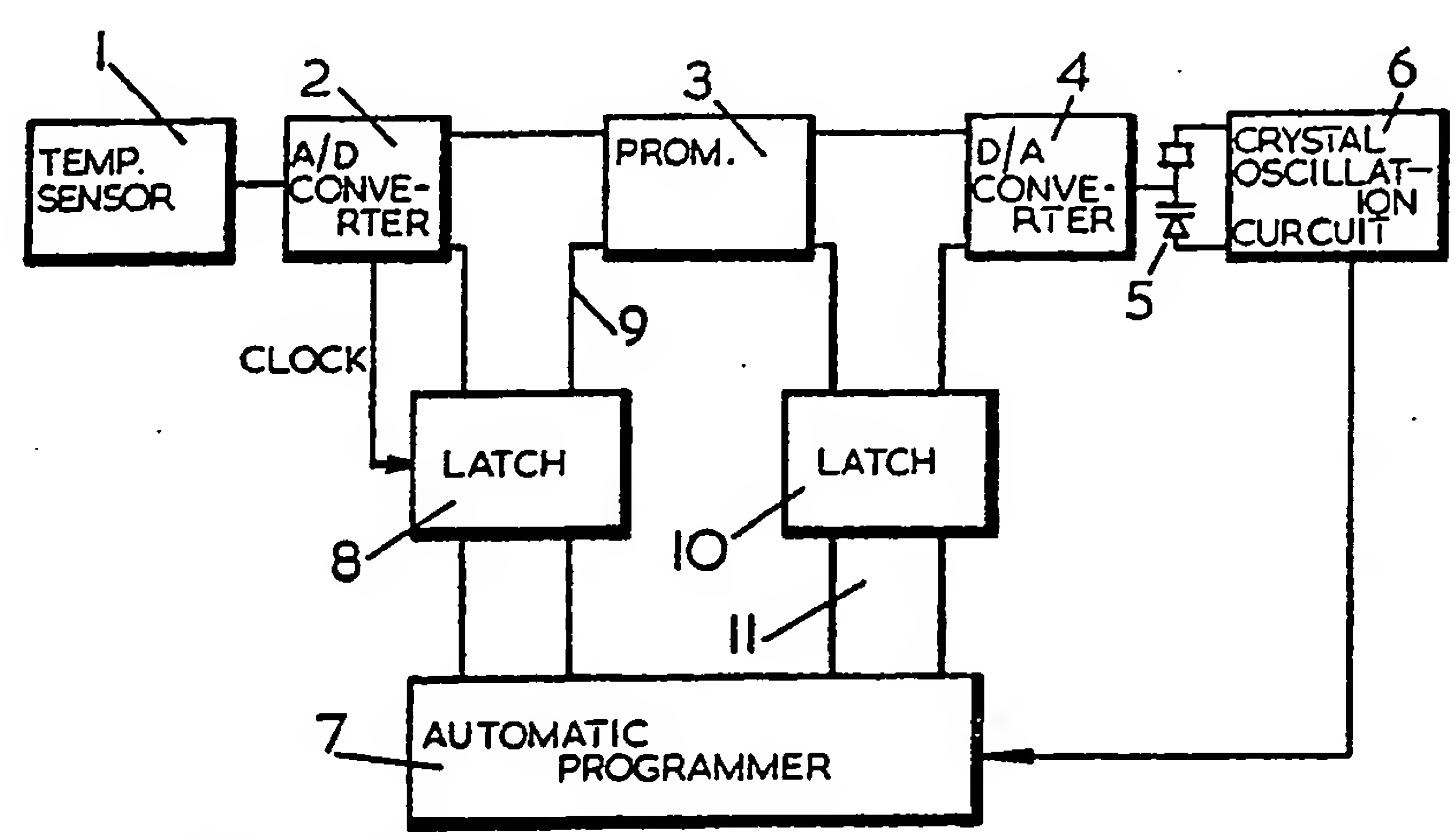


FIG. 2

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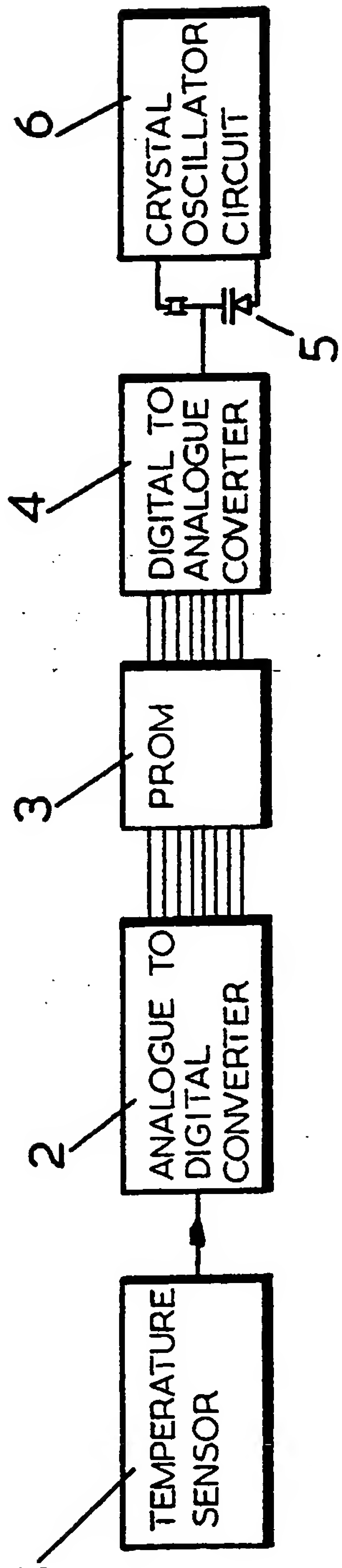


FIG. 1

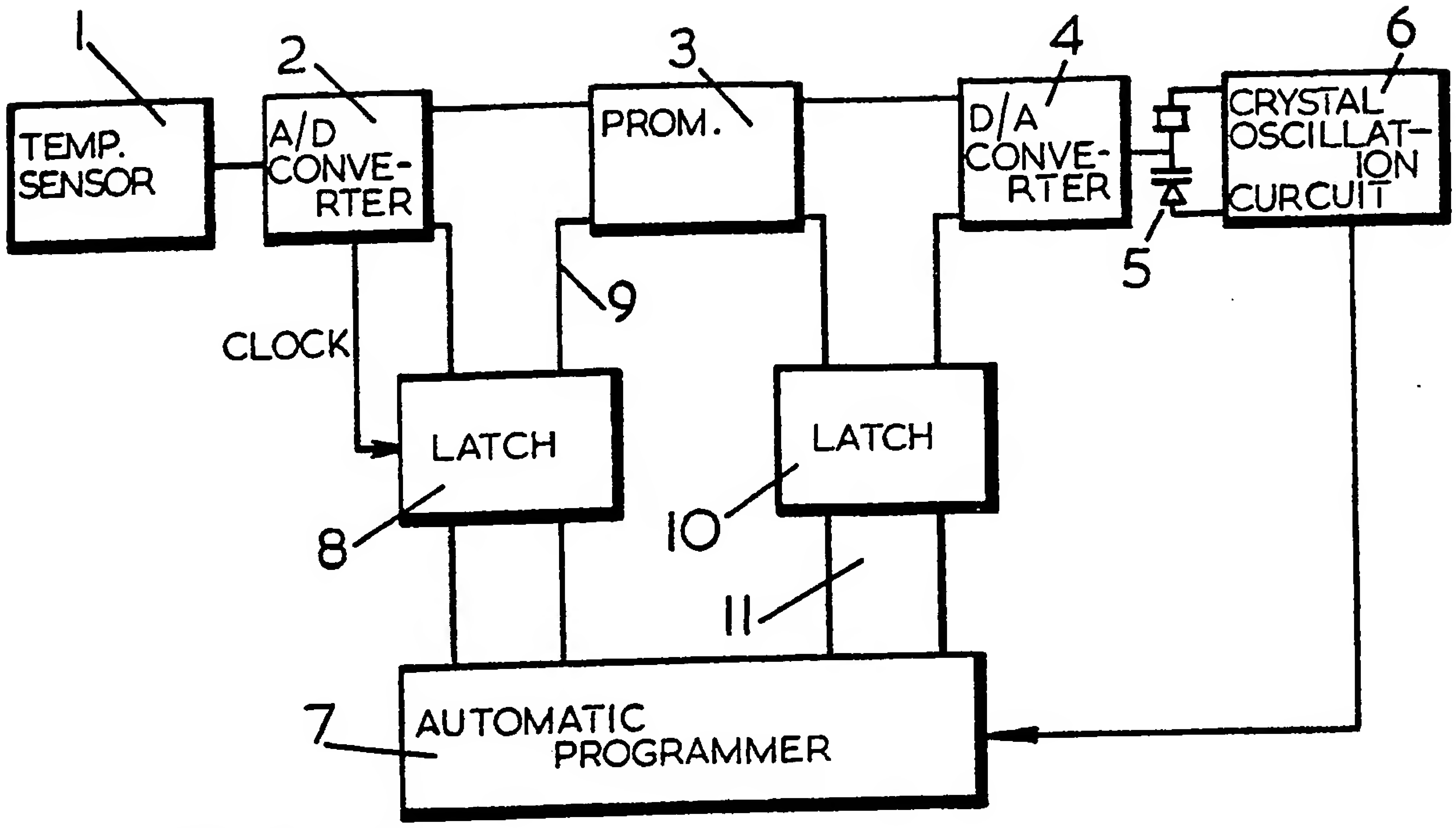
1
2
3
4
6
TEMP. SENSOR
A/D CONVE-RTER
PROM.
D/A CONVE-RTER
CRYSTAL OSCILLAT-ION CURCUIT
5
9
CLOCK
LATCH
LATCH
8
10
11
7
AUTOMATIC PROGRAMMER

FIG. 2

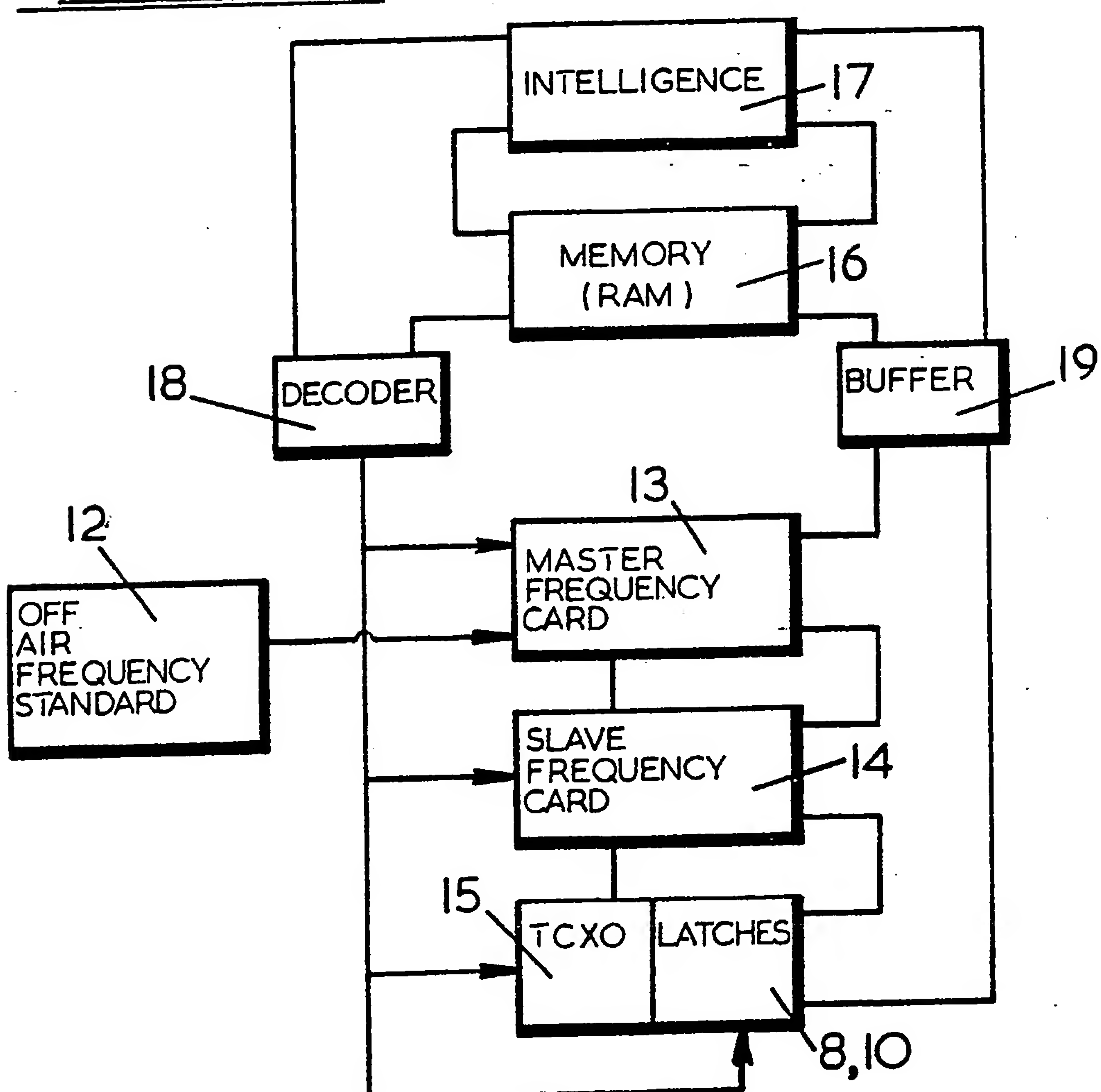
INTELLIGENCE
17
MEMORY (RAM)
16
18
DECODER
BUFFER
19
13
12
MASTER FREQUENCY CARD
OFF AIR FREQUENCY STANDARD
SLAVE FREQUENCY CARD
14
15
TCXO
LATCHES
8,10

FIG. 3

SPECIFICATION
**Temperature compensated crystal oscillators**

The present invention relates to temperature compensated crystal oscillators.

The frequency of vibration of a quartz crystal is a temperature dependent function. Consequently the frequency at which an oscillator, deriving its frequency of oscillation from a quartz crystal, oscillates is dependent upon the temperature of the quartz crystal. Therefore, in order to obtain an accurately defined frequency of oscillation over a range of temperatures it is necessary to compensate for the temperature dependent properties of the crystal.

A quartz crystal oscillator can be made to change its frequency of oscillation by varying a reactance placed in series with the crystal. If this reactance is made temperature dependent a means of temperature compensation can be obtained. The simplest type of known temperature compensated crystal oscillator (TCXO) employs a negative temperature coefficient capacitor in series with the crystal. Unfortunately with such an arrangement temperature compensation can only be achieved over substantially linear portions of the crystal frequency/temperature characteristic.

In another known arrangement the voltage across a varactor diode placed in series with the crystal is varied in accordance with the temperature sensed by a temperature to voltage transducer. Since the reactance of the varactor diode is a function of the voltage across it, the reactance of the varactor diode is thus made temperature dependent and the crystal oscillator is temperature compensated. It is however difficult to match the characteristics of varactor diodes to those of quartz crystals.

Unfortunately each quartz crystal together with its oscillation circuit has its own unique non-linear frequency/temperature characteristic which makes it difficult to design temperature compensating circuits of the above mentioned types which are sufficiently flexible to be applicable to most crystal oscillator units.

In order to compensate for the frequency/temperature characteristics of individual crystals the use of digital techniques has been proposed in for example British Patent Specification 1,380,456. According to these proposals, a temperature dependent voltage, derived from a temperature to voltage transducer exposed to the same temperature as a crystal, is input to an analogue to digital converter which produces at its output a digital word representative of the temperature sensed. This digital word is used to address a memory into which has been pre-programmed a digital compensation word appropriate to the sensed temperature. The compensation word is then input to a digital to analogue converter which produces at its output a compensating voltage. This temperature representative voltage is passed through a transfer function generator to produce at its output the temperature compensation signal required by the varactor diode to effect temperature compensation of the oscillator within the temperature range specified.

In such a system no prior calculations are required to design a temperature compensating unit which matches the particular characteristics of an individual crystal. Indeed, the system is flexible enough to compensate for the particular characteristics of almost any crystal.

To produce the digital compensation words stored at each temperature address the TCXO is placed in an environemental chamber, whose temperature is then varied over the specified range of the oscillator. Each time the least significant bit (L.S.B.) of the output of the analogue to digital converter changes the address is latched to the memory. By the use of switches a compensating word is then fed to the digital to analogue converter which produces the desired compensation in the frequency of oscillation. This compensation word is then programmed into the memory of the TCXO at the appropriate address.

The determination of the appropriate compensation word and its programming into the correct memory address is undertaken manually. This is time consuming and tedious, with considerable risk of incorrectly programmed memory locations and so is not commercially viable.

It is an object of the present invention to provide means whereby the correct compensation word may be determined and stored in the appropriate address automatically, thus mitigating and obviating the above mentioned problems and allowing the mass production of digitally compensated TCXO's.

According to the present invention there is provided an apparatus for programming the memory of a temperature compensated crystal oscillator of the type comprising a crystal oscillator circuit, an oscillator frequency control circuit, means for sensing the ambient temperature to which the crystal oscillator is exposed, an analogue to digital converter connected to the output of the temperature sensing means, a programmable memory addressed by the output of the analogue to digital converter, and a digital to analogue converter connected to the memory for supplying to the oscillator frequency control circuit a temperature compensation signal dependent upon the data supplied from the memory location addressed by the analogue to digital converter, characterised in that the programming apparatus comprises means for varying the ambient temperature, means for monitoring the output of the digital to analogue converter, means for monitoring the output frequency of the crystal oscillator circuit, means for providing a temperature compensation input to

predetermined desired freuqency, and means for storing in the memory location addressed by the output of the analogue to digital converter data representative of the temperature compensation input to the digital to analogue converter which results in the predetermined desired crystal oscillator circuit output frequency, whereby after programming the appropriate temperature compensation signal is selected from the memory by the analogue to digital converter in dependence upon the ambient temperature.

An embodiment of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Fig. 1 shows a temperature compensated crystal oscillator of the type which may be programmed in accordance with the present invention;

Fig. 2 illustrates the programming of the crystal oscillator of Fig. 1; and

Fig. 3 is a schematic diagram of an apparatus for effecting programming of the crystal oscillator of Fig. 1.

Fig. 1 shows a schematic diagram of a digitally controlled temperature compensated crystal oscillator (TCXO). A temperature dependent voltage from a temperature sensor 1 is input to an analogue to digital converter 2 which produces at its output a digital word representative of the sensed temperature. The digital word allows access to a particular temperature address within an adressable memory of the PROM type having for example a capacity of 256 addresses. Over a specified temperature range of, for example, —20 to +80°C there will be 256 discrete temperature ranges resulting in a change of address to the memory with every change in temperature of 0.4°C, the temperature "step". For each particular address the memory 3 has pre-programmed into it a digital compensation word which when input to a digital to analogue converter 4 produces at its output a compensating voltage. When applied to a varactor diode 5 the compensating voltage effects the temperature compensation required by the crystal oscillator circuit 6.

The compensation word may be pre-programmed into the memory of the TCXO manually. Figure 2 shows a schematic diagram of automatic programming means embodying the invention for programming the TCXO of Fig. 1.

During automatic programming, the TCXO is placed in an environmental chamber (not shown) and the PROM 3 resident in the TCXO is disabled. The temperature inside the chamber is increased continuously at a predetermined rate. An automatic programmer 7 is used to simulate the behaviour of PROM 3. A digital word representative of the temperature sensed in the environmental chamber by the temperature sensor 1 and output from the analogue to digital converter 2 is clocked into a latch 8 through data bus 9. The output of latch 8 is supplied to automatic programmer 7 which then writes a trial 11, examines the resulting frequency of oscillation of the crystal oscillator 6 over a predetermined period of time and adjusts the compensation word if the measured frequency is not within a desired frequency range. The automatic programmer 7 detects each temperature step change in temperature sensed by the temperature sensor 1 by comparing old and new readings from the analogue to digital converter 2. Each temperature step change in temperature is taken in sequence, and the resulting compensation words, once determined, are stored in corresponding sequence, in a memory field in the automatic programmer 7. Once determination of the compensation words is completed for the entire temperature range the complete table of compensation words stored in the memory field can be block transferred to the resident PROM 3 in the TCXO allowing, if required, programming of the PROM 3 to occur subsequently outside the temperature chamber environment.

Determination of the first compensation word is accomplished using a successive approximation technique in which for example, an 8 bit compensation word the automatic programmer 7 makes a maximum of 8 attempts to determine the correct compensation word. For subsequent compensation words the automatic programmer 7 uses a trend technique, based on stored historical data in the intelligence 17, to make a close estimate of the next compensation word which is then incremented or decremented as necessary.

A reduced resolution TCXO may be obtained by determining a new compensation word on every change of the second least significant bit of the digital word representing sensed temperature instead of the least significant bit of the same digital word.

The automatic programmer 7 is capable of simultaneously programming a number of TCXO's of possibly differing specification during each programming period.

The principle of operation of an automatic programmer capable of simultaneously programming a number of TCXO's will now be described with reference to Fig. 3. To clarify the drawing, only one TCXO is shown in Fig. 3.

Ideally the automatic programmer would also control the temperature rise of the environmental chamber (not shown), in which the TCXO is placed, in order to ensure that the correct compensation word is determined before moving onto the next significant temperature. However, the environmental chambers usually used for this purpose only allow a pre-programmed linear ramp rate of temperature increase, and when using such a chamber it is important to establish the correct compensation word quickly in order that the time allowed at each significant temperature range is not exceeded. To obtain the necessary frequency resolution examination of the crystal oscillator frequency may take as long as 10 seconds. In a typical environmental chamber having a rate of increase in temperature of 0.25°C per minute and

average of 90-100 seconds is allowed to determine each compensation word. This period of time is, on the whole sufficient where it is required to determine the compensation word at a particular significant temperature for only one TCXO, however, for two or more TCXO's, this time restraint becomes a significant handicap if only one frequency determining means is provided to monitor all the TCXO's during any one programming period.

Referring to Fig. 3, an Off Air Frequency Standard 12 supplies a known frequency signal to a master frequency card 13. To enable a number of TCXO's to be simultaneously programmed, the single master frequency card 13 is used to synchronously reset and time a dedicated slave card 14 for each TCXO 15 under production. Each dedicated slave card 14 provides frequency counting means, in the form of a cascaded string of BCD counters, for its associated TCXO 15 over an accurately timed period derived by the master frequency card 13 from the Off Air Frequency Standard 12. The accurately timed period over which the TCXO frequency of oscillation is examined by the dedicated slave card 14 is software programmable to produce either 1 or 10 second examination periods.

A microprocessor represented by RAM memory 16 and intelligence 17 is connected to the master frequency card 13, the slave frequency cards 14 and the TCXO 15 via decoder 18 and buffer 19. Where it is required to simultaneously programme a member of TCXO's it is necessary that the microprocessor is able to select any one of the TCXO's which it is programming in order that it can read and input data. Further to this it is also necessary for the microprocessor to be able to select any one of the input/output devices associated with each TCXO being programmed in order to read or input data from or to any of them. These input/output devices external to the microprocessor but associated with the programming of each TCXO include the latches 8 and 9, latches and buffers (not shown) associated with each dedicated slave card 14 and latches and buffers (not shown) associated with the master clock 13. So that any particular device external to the microprocessor may be selected the entire system is memory mapped. Each buffer and latch is allocated its own unique address within the microprocessor memory 16. However, for the microprocessor to be able to operate any one of these devices it is necessary for each unique address to be decoded. The decoder 18 is provided for this purpose, decoding each address from the memory and thus producing a device selection system. In this way a number of TCXO's may all be simultaneously programmed by the one microprocessor by the allocation to each TCXO and its associated programming devices of unique addresses.

A current buffer 19 is provided between the microprocessor, and the other cards and the TCXO's.

A semiskilled operator may be used to initiate a production run, having installed the TCXO's in the environmental chamber and set the temperature range. Calling and running the programme enters the operator into a data input loop, which prompts the operator for all the required production parameters such as nominal frequency and frequency tolerance. The software may be programmed to include tests for all known response failures from the TCXO's and will exclude a faulty unit from further programming during a production run, without affecting the rest of the batch. The operator may be informed of such events by means of a printout system.

This system also allows for the reprogramming of old TCXO's which have experienced frequency drift due to the "ageing" process present in all piezoelectric devices such as quartz crystals. The old TCXO is placed in the simulated temperature environment and the apparatus monitors its performance, reprogramming only the maverick temperature/frequency steps.

CLAIMS

1. An apparatus for programming the memory of a temperature compensated crystal oscillator of the type comprising a crystal oscillator circuit, an oscillator frequency control circuit, means for sensing the ambient temperature to which the crystal oscillator is exposed, an analogue to digital converter connected to the output of the temperature sensing means, a programmable memory addressed by the output of the analogue to digital converter, and a digital to analogue converter connected to the memory for supplying to the oscillator frequency control circuit a temperature compensation signal dependent upon the data supplied from the memory location addressed by the analogue to digital converter, characterised in that the programming apparatus comprises means for varying the ambient temperature, means for monitoring the temperature represented by the output of the digital to analogue converter, means for monitoring the output frequency of the crystal oscillator circuit, means for providing a temperature compensation input to the digital to analogue converter, means for adjusting the temperature compensation input until the monitored output frequency is at a predetermined desired frequency, and means for storing in the memory location addressed by the output of the analogue to digital converter data representative of the temperature compensation input to the digital to analogue converter which results in the predetermined desired crystal oscillator circuit output frequency, whereby after programming the appropriate temperature compensation signal is selected from the memory by the analogue to digital converter in dependence upon the ambient temperature.

2. An apparatus according to claim 1,

input to the digital to analogue converter by respective latches.

3. An apparatus according to claim 2, comprising a master frequency card connected to receive an Off Air Frequency Standard Signal, a slave frequency card for counting the number of cycles of the oscillator output singal for a predetermined period determined by the master frequency card, and means for supplying the results of the count to the microprocessor.

4. An apparatus according to claim 2 or 3, wherein the microprocessor is arranged to adjust the compensation input by a successive approximation technique.

5. An apparatus for programming the memory of a temperature compensated crystal oscillator substantially as hereinbefore described with reference to the accompanying drawings.

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